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Strengthening of reinforced concrete beam column joint under seismic loading using ANSYS

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ABSTRACT: *The behavior of reinforced concrete moment resisting frame structures in recent earthquakes all over the world has highlighted the consequences of poor performance of beam column joints. Beam column joints in a reinforced concrete moment resisting frame are crucial zones for transfer of loads effectively between the connecting elements in the structure. The reversal of forces in beam-column joints during earthquakes may cause distress and often failure, when not designed and detailed properly. In the present study, finite element modeling of four types of exterior beam-column joint specimens is done by using ANSYS10.0.The first specimen confirms to the guide lines of IS 13920: 1993 for seismic resistant design. Second one is detailed with additional diagonal cross bracing bars at joints and beam reinforcements. Third with cross bars in beam region of 6mm instead of cross bars in joint. Fourth specimen with cross bars of 8mm instead of 6mm in beam region. The specimens are subjected to similar reverse cyclic loading to simulate earthquake loading in structures. The specimen with cross bars of 8mm in beam region shows better performance under reverse cyclic loading.*

Keywords: *Beam column joint, cyclic load, ductility, finite element models, Reinforced Concrete, seismic loading.*

I. INTRODUCTION

The beam column joint is the crucial zone in a reinforced concrete frame. It is subjected to large forces during severe ground shaking and its behavior has a significant influence on the response of the structure. The assumption of joint being rigid fails to consider the effects of high shear forces developed within the joint. The shear failure is always brittle in nature which is not an acceptable structural performance especially in seismic conditions.

Understanding the joint behavior is essential in exercising proper judgments in the design of joints. Therefore it is important to discuss about the seismic actions on various types of joints and to highlight the critical parameters that affect joint performance with special reference to bond and shear transfer.

The anchorage length requirements for beam bars, the provision of transverse reinforcement and the role of stirrups in shear transfer at the joint are the main issue. A study of the usage of additional cross-inclined bars at the joint core shows that the inclined bars introduce an additional new mechanism of shear transfer and diagonal cleavage fracture at joint will be avoided. However, there were only limited experimental and analytical studies for the usage of non-conventional detailing of exterior joints. In spite of the wide accumulation of test data, the influence of cross inclined bars on shear strength of joint has not been mentioned in major international codes. In this work an attempt has been made to improve the confinement of core concrete without congestion of reinforcement in joints.

The performance of exterior joint assemblages designed for earthquake loads as per IS 1893:2002 are compared with the specimens having additional cross bracing bars provided on two faces of joint as confining reinforcements. The experimental results found out by K.R. Bindhu and K.P. Jaya [1] is validated with the analytical model developed using finite element software package ANSYS10.0.

II. DETAILS OF SPECIMENS

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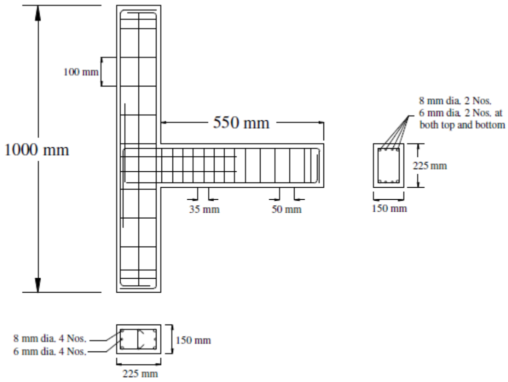
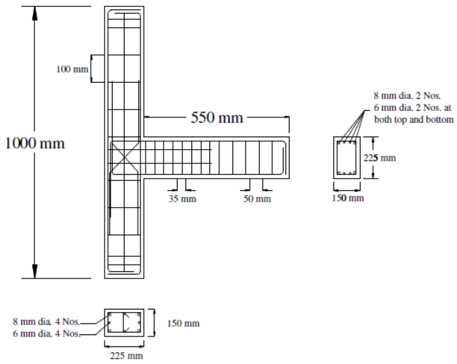
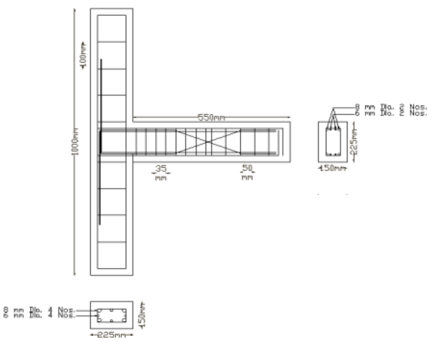
The beam column joints had identical beam and column sizes. The beams were 225mm deep by 150 mm wide and columns were 225 mm deep by 150 mm wide. Figure 1 shows the cross section and reinforcement configurations for the specimens. Ordinary Portland cement (53 grade), sand passing through 4.75 mm IS sieve and crushed granite stone of maximum size not exceeding 8 mm were used for the concrete mix. The 28-day compressive strength of the concrete cube was 44.22N/mm^2. Steel bars of yield stress 432N/mm^2 were used as main reinforcement and stirrup. The cover for the longitudinal bars was maintained at 15mm for all the units. Adequate development lengths as per the code requirement were given for the beam longitudinal bars and cross bracing bars to take care of the pull out force.



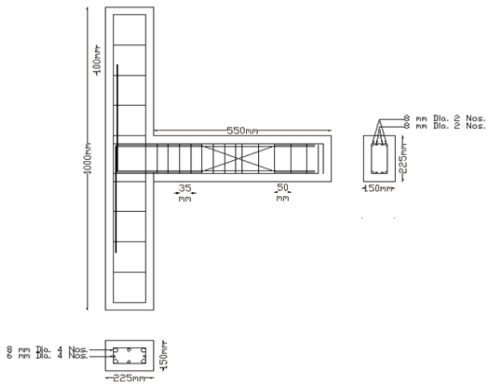
(a)Without Cross Bracing bars



(b) With Cross Bracing Bars



(c) Cross bars of 6mm in beam region



(d) Cross bars of 8mm in beam region

Figure 1. Reinforcement details of specimen of (a) Without Cross Bracing bars and (b) With Cross Bracing Bars. (c)Cross bars of 6mm in beam region. (d) Cross bars of 8mm instead of 6mm in beam region.

III. ANALYTICAL MODELING

The numerical model represents only half of the beam column joint through width used in the experimental investigation. The symmetry boundary conditions are used in order to simulate the tested joint sub assemblages adequately. The beam column joint was modeled in ANSYS 10.0 [9] with Solid 65, Solid 45 and Link8 elements. The Solid 65 element was used to model the concrete and Solid 45 element was used to model hinge support at base. These elements have eight nodes with three degrees of freedom at each node- translations in the nodal x, y and z directions. The Link8 element was used to model the reinforcement. This three- dimensional spar element has two nodes with three degrees of freedom at each node – translations in the nodal x, y and z directions.

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3.1 Sectional Properties (Real Constants)

The real constants considered for Solid 65 element were volume ratio and orientation angles. Since there was no smeared reinforcement, the real constants (volume ratio and orientation angle) were set to zero. No real constant sets exist for Solid 45 element. The real constants considered for Link8 element are cross sectional area and initial strain.

3.2 Material Properties

The material properties used in the model are given in Table 1. The average 28-day cube strength (f_{cu}) of test specimens was 44.22 MPa. The relationship of cylinder strength (f_{cu}') and cube strength (f_{cu}) as ($f_{cu}' = 0.8\, f_{cu}$) and thus the ultimate compressive strength (f_c') was 35.376 MPa. The uniaxial tensile cracking stress of concrete (f_t) is determined using Equation (1)

$$f_t = 0.623\sqrt{f_c'} \qquad (1)$$

The yield stress and tangent modulus of reinforcement bars were obtained from laboratory test.

$$f = \frac{E\varepsilon}{1+\left(\frac{\varepsilon}{\varepsilon_0}\right)^2} \qquad (2)$$

Where,
f = stress at any strain ε
ε_0 = strain at the ultimate compressive strength f_c'
E = a constant (same as initial tangent modulus)
Table 1. Material properties defined in model

Material model No.	Element type	Material properties	
1	Link-Spar8	Linear Isotropic EX PRXY Bilinear Kinematic Yield stress Tangent Modulus	 $2.1\text{x}10^{11}$N/m^2 0.3 $432\text{x}10^{6}$N/m^2 $847\text{x}10^{6}$N/m^2
2	Solid - Concrete65	Linear Isotropic EX PRXY Concrete Shear transfer coefficient for open crack Shear transfer coefficient for closed crack Uniaxial tensile cracking stress	$3.252\text{x}10^{10}$N/m^2 0.15 0.2 0.9 $3.71\text{x}10^{6}$N/m^2
3	Solid 45	Linear Isotropic EX	$2.1 \text{ x } 10^{11}$ N/m^2 0.3

3.3 Modeling of Beam-Column Joint

The beam-column joint is modeled in ANSYS10 software using the above element types and the material properties. Only half of the system was modeled through the thickness so that the symmetry conditions were used. Some of the modeling details are shown in the Figure 2. The axial load is applied on the top of the column with hinged base and a roller support at 50 mm from the top. The load on the beam is applied at a distance of 50 mm from the free end. The models were analyzed with monotonic loadings in the upward and downward direction.

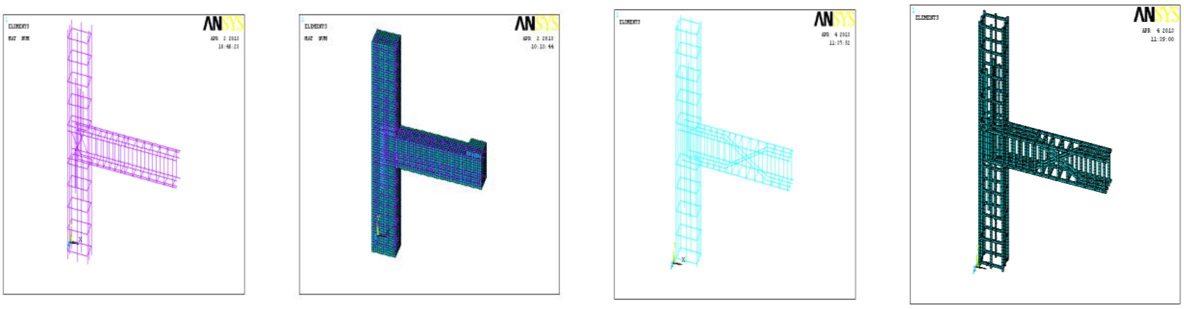

Figure 2. Modeling details in ANSYS

IV. RESULTS

The displacement of the specimen at yield load and ultimate load is shown in the Table 2 and Table 3. The table shows the comparison of the deflections carried out by using Ansys model for the fours specimens. A clear idea of the behavior of the specimen can also be drawn from the table.

Table 2. Displacement of the specimen at Yield Load

	Specimens			
Type of Loading	IS:13920	Cross bars in joint region	6mm cross bars in Beam region	8mm cross bars in Beam region
Downward Loading	4.562	3.116	2.639	2.417
Upward Loading	5.415	3.116	2.639	2.425
Average Displacement	4.9885	3.116	2.639	2.421

Table 3. Displacement of the specimen at Ultimate Load.

	Specimens			
Type of Loading	IS:13920	Cross bars in joint region	6mm cross bars in Beam region	8mm cross bars in beam region
Downward Loading	23.639	23.667	24.332	25.465
Upward Loading	23.639	23.667	24.332	25.465
Average Displacement	23.639	23.667	24.332	25.465

Displacement ductility of specimen from the Ansys model is shown in the table. 4 . It can be observed that the displacement ductility is enhanced for cross bars of 8mm in beam region specimens than that of other three specimens. The displacement ductility for the specimen with cross bars of 6mm in beam region is increased by 17.62% as compared with the cross bracing bars in the joint region. Also the displacement ductility is further increased in case of cross bars of 8mm in beam region by 27.79% as that of the cross bars in joint region.

Table 4: Displacement ductility of specimens from ANSYS model

	Displacement				Displacement ductility		Average Displacement ductility
	Yield		Ultimate				
Specimen	Downward direction	Upward direction	Downward direction	Upward direction	Downward direction	Upward direction	

IS:13920	4.562	5.415	23.639	23.639	5.181	4.365	4.773
Cross joint	3.116	3.116	23.667	23.667	7.595	7.5953	7.595
6mm cross bars in Beam region	2.639	2.639	24.332	24.332	9.2201	9.2201	9.2201
8mm cross bars in Beam region	2.417	2.425	25.465	25.465	10.5357	10.501	10.5183

V. CONCLUSION

The following conclusions can be stated based on the evaluation of the analyses of reinforced concrete beams column joint.

(1) The test specimens with diagonal confining bars of 8mm in the beam region have shown better performance, exhibiting higher strength with minimum cracks in the joint. All the specimens failed by developing tensile cracks at interface between beam and column. The joint region of specimens of cross bars is free from cracks except some hair line cracks which show the joints had adequate shear resisting capacity.

(2) From the analytical study it is observed that the provision of cross diagonal reinforcement in beam region increased the ultimate load carrying capacity and ductility of joints in the both upward and downward loading conditions.

(3) The increase in reinforcing bar cross section has a significant effect on the flexural strength.

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